**Non-Invasive Level Estimation of Blood Glucose and Haemoglobin Using Neural Network**

$$SMVEC; Puducherry;India$$

$$1.Romaric Sallustre, Department of Instrumentation and Control Engineering,$$

$$ Sri Manakula Vinayagar Engineering College, Puducherry, India$$

$$2.Divakaran D, Department of Electronics and Communication Engineering,$$

$$ Sri Manakula Vinayagar Engineering College, Puducherry, India$$

$$3. Dr. K. Naveen Kumar,Assistant Professor,$$

$$ Department of Instrumentation and Control Engineering$$

Sri Manakula Vinayagar Engineering College, Puducherry, India

**ABSTRACT**

Diabetes is one of the prominent diseases around the world. Presently, invasive techniques need a finger-prick blood sample. A repetitively painful procedure that produces the chance of infection. A device for blood Hemoglobin measurement was designed and developed without pricking the blood. This non-invasive device is based on principle of NIR spectroscopy technique with specific short wavelengths for detection of Hemoglobin molecule. The proposed technique is implemented using emitters and Camera of particular specifications and ratings. The data acquisition module is also implemented with combinations of emitters and Camera to collect the data. The proposed non-invasive device is examined by placing fingertip into the embedded clips which contain emitters and detectors. Hence, continuous blood Hemoglobin monitoring is possible through developed prototype. The mechanism of Hemoglobin detection is that when light of specific wavelengths passes through the object, then received resultant light is corresponds to change in blood Hemoglobin concentration. These collected spectrums are interpreted in the form of blood Hemoglobin concentration using a machine learning-based CNN model.

*Index Terms*—*Non-Invasive Method, Blood Hemoglobin, Near-infrared (NIR) spectroscopy, CNN*

 **1 INTRODUCTION**

422 million diabetic people have been reported in 2019 according to the WHO database. The people are found in low- and medium-income countries. In 2019, 69.2 million Indians of the population had type 2 diabetes. Approximately 2.35 million adults have Type 1 diabetes. Diabetes takes place when a person faced difficulty in balancing the body Hemoglobin level in different prandial states. Diabetes is caused by the deficiency of insulin with respect to the generated Hemoglobin in the body. It may be due to the demolition of insulin which is produced by beta cells in the pancreas. Diabetes may also be caused by insulin resistance. This is a condition in which the muscles, fat and liver cells of the body do not consume insulin effectively.

 Diabetes is classified into three parts: Type 1 diabetes, Type 2 diabetes and gestational diabetes. In type 1 diabetes, the immune system of the body attacks and destroys the cells of the pancreas which produce insulin. This results in the affected person who will be unable to generate insulin naturally. Type 2 diabetes is the most common diabetic stage which is most commonly seen in the people over the world. In this type of diabetes, the pancreas will be able to generate some amount of insulin. Gestational diabetes occurs in women in the later stages of pregnancy. Most common symptoms of diabetes are the excretion of urine within short durations, consistently hungriness, thirsty, unexpected weight loss, tiredness and vision changes. The long duration of diabetes without any treatment may cause kidney disease, stroke, heart disease, nerve damages and blindness. After being these problems, probability of death with diabetes has become 50% higher than without diabetes in adults. Diabetes may be controlled through physical exercise, diet, and proper use of insulin regimen. Oral medications are also useful to control for an early stage of diabetes. Controlling of diabetes also includes reduction of risk factors for cardiovascular disease such as lipid profile, high systolic and diastolic blood pressure. In most cases of adults, 5% Type 1 diabetic patients have been considered approximately in all diagnosed case. Whereas, 90-95% Type 2 diabetic patients have been considered for treatment. Type 1 diabetic patient must have insulin to control the blood Hemoglobin level. Type 2 diabetic patients can control their Hemoglobin level by following an optimized diet with medication and a regular physical exercise schedule. By using a noninvasive device for continuous blood Hemoglobin measurement, the patient can have a proper dose of insulin or other kind medication and can control the blood Hemoglobin level during physical activities. The certain meal is also needed to control diabetes.

 **2 PROBLEM DEFINITION**

Presently available invasive glucometers and wearable minimally invasive patches are not advisable for frequent monitoring. These would cause trauma due to pricking the skin multiple times. Therefore, non-invasive approaches are reported as precise solutions in terms of continuous Hemoglobin measurement. The available noninvasive devices are also not precise in terms of Hemoglobin measurement of diabetic patients. Some devices are precise but these are limited to the Hemoglobin measurement range (preferred range is 90-150 mg/dl). This is also not advisable for day to day measurement purpose. Hence, it is necessary to develop the device which can measure the blood Hemoglobin non-invasively for all kind of people (healthy and diabetic).

**3 NON-INVASIVE METHOD**

The goal of this paper is to explore a unique approach to measure blood Hemoglobin without pricking the blood. A device has been designed with the implementation of the proposed technique. The proposed device is a system on PCB along with the data acquisition module. The Camera and components which are used to implement the proposed technique are comparatively low cost and easily available in the market. Because of this, the solution will be cost-effective. The Camera is light weighted and can be worn on the finger and wrist just like a wearable system. The non-invasive system is required to design which should be user friendly and supports to continuous Hemoglobin monitoring (CHM). The Medical framework is also required for diagnosis and treatment of remote located diabetic patient. The closed loop system is needed to design which measures the Hemoglobin and provide the insulin dose to control the Hemoglobin of diabetic patient.

**3.1 RELATED WORK**

Many commercial continuous blood Hemoglobin measurement devices use cost-effective electrochemical sensors [11]. They are available to respond quickly for Hemoglobin detection in blood [12]. Lancets (for pricking the blood) is used at the primary stage for blood Hemoglobin monitoring for various commercial devices available in the market [13]. The frequent measurement through the process is so much panic due to picking the blood sample from the fingertip more than 3-4 times in a day for frequent monitorings[14]. A low-invasive amperometric Hemoglobin monitoring biosensor has been proposed using fine pointed Hemoglobin oxidase immobilized electrode which doesn’t require more than 1mm in length to be inserted in skin [15]. The photometric approach has been explored for Hemoglobin measurement using small blood volumes [16]. The issue of high volume of pricking blood has been solved by this system for testing. A fully implanted first-generation prototype sensor has been presented for long-term monitoring of subcutaneous tissue Hemoglobin [17]. This wearable sensor which is integrated as an implant is based on a membrane containing immobilized Hemoglobin oxidase and catalase coupled to oxygen electrodes, and a telemetry system.

**3.2 Minimally Invasive Methods**

Implantable sensors have been deployed for continuous Hemoglobin monitoring [18]. Biosensors have been designed for patient use massively and successfully for one time invasive [19]. Wearable minimally invasive microsystem has been explored for Hemoglobin monitoring [20]. A microsystem has been presented for Hemoglobin monitoring which consists of microfabricated biosensor flip-chip bonded to a transponder chip [21]. The output signal has been measured by this transponder chip of the biosensor and transmitted the measured data back to the external reader. A method has been discussed to reduce the frequency of calibration of minimally invasive Dexcom sensor [22]. An artificial pancreas has been represented along with a Hemoglobin sensor to control diabetes [23]. But, approaches based semi-invasive devices have not been tried for real-time application. These wearable microsystems are neither painless nor cost-effective solutions.

**3.3 Non-invasive Methods**

Non-invasive approaches of measurement are more advanced compared to the current invasive method to make the painless device [14], [15]. The portable system of measurement (SoM) of the non-invasive Hemoglobin measurement device is desirable for smart healthcare system [10]. A lot of approaches have been introduced for Hemoglobin measurement [16]. Non-invasive approaches of measurement are more advanced compared to the current invasive method [14], [15]. The optical method is more reliable, cost-efficient for Hemoglobin measurement according to the analysis of researchers [17], [18]. There are varieties of various optical techniques for noninvasive measurement such as photoacoustic spectroscopy [19], polarimetric, near infer-red spectroscopy, Raman spectroscopy and scattering spectroscopy [20]. For the development of a non-invasive measurement device, it is considered by the researcher that the device would be much convenient for the user’s perspective [21]. In this way, improvement of the accuracy and reliability of these devices have been considered as essential objectives. Calibration and blood to interstitial Hemoglobin dynamics have been considered for the accuracy of continuous Hemoglobin monitoring system [34]. Several calibration algorithms have been developed and implemented for portable setup. Sometimes, accuracy is not considered as a serious issue as per reliability and error detection [16]. But, reliability has been approved for main requirements and tried to improve it [17]. In the further direction, self-monitoring system is embedded and included detection abrupt faults [18]. A lot of work has also been done on fault detection for continuous monitoring.

**3.4.1 Near-Infrared Spectroscopy**

 Infrared spectroscopy (IR spectroscopy or Vibrational Spectroscopy) involves the interaction of infrared radiation with matter[40]. It covers a range of techniques[41]. It is based on scattering, absorption and reflection spectroscopy [22]. The absorption of IR waves causes the generation of vibrations of the molecular atom and causes of band spectrum which are usually expressed by wavenumber cm−1 [23]. In this technique, the light in the near-infrared range (700nm – 2500nm) is passed through the object (ear lobe or finger) [24]. The passed light through the finger or ear lobe interacted with the components of blood and gets reflected, absorbed and scattered [25]. The penetration depth will be varied with a change in wavelength [26]. According to Beer-Lambert law, the attenuation of light in tissue or vessel relates the intensity of light, reflection, scattering coefficient and path length of light through tissue or vessel [27]. Attenuation occurs due to absorption of scattering of light [28]. The value of absorption coefficient depends upon the change in Hemoglobin concentration [29]. The value of Hemoglobin concentration in blood vessel could be indicated due to change in intensity of transferred light through the vessel [30]. The change in Hemoglobin concentration is measured through light detector [31].

1. **PROPOSED SYSTEM**

# In this project, proposing approaches for blood Hemoglobin level measurement with the aim of recommending data collection techniques, signal extraction processes, feature calculation processes, machine-learning algorithms for developing a noninvasive Hemoglobin level estimation using a smartphone. There is worldwide demand for an affordable Hemoglobin measurement solution, which is a particularly urgent need in developing countries. The smartphone, which is the most penetrated device in both rich and resource-constrained areas, would be a suitable choice to build this solution. This Project proposes a noninvasive Hemoglobin level measurement processes. Also its compared the variation in data collection sites, biosignal processing techniques, theoretical foundations, photoplethysmogram (PPG) signal and features extraction process, machine-learning algorithms, and prediction models to calculate Hemoglobin levels. This analysis was then used to recommend realistic approaches to build a smartphone-based point-of-care tool for Hemoglobin measurement in a noninvasive manner A noninvasive (without blood sample collection) approach involves data obtained from image sensors, spectroscopic information, and output of a photoplethysmography (PPG) sensor to calculate the Hb level.

#  A smartphone-based POC tool as a potential alternative to invasive clinical blood testing is rapidly attracting attention because of the advantages of availability, user-friendliness, and easy attachability to different biosensing devices. The fingertip area is one of the best data collection sites from the body, followed by the lower eye conjunctival area. Near-infrared (NIR) light-emitting diode (LED) light were identified as potential light sources to receive a Hemoglobin response from living tissue. PPG signals from fingertip videos, captured under various light sources, can provide critical physiological clues. The features of PPG signals captured under NIR LED are considered to be the best signal combinations following a dual-wavelength theoretical foundation. The PPG signal is generated from each video, and multiple characteristic features are then extracted from the PPG signal, its derivatives and from Frequency analysis. genetic algorithms (GA) has been used to select the optimal features (Feature selection).

#  Finally, CNN based models have been developed to estimate the blood Hemoglobin (Hb) levels from the selected features. The approach expected to provides the best-estimated accuracy of around 98%.

#

# Figure1.1. Architecture Diagram of proposed System.

# **4.1 NIR spectroscopy**

#

# Figure1.2 NIRS based Hemoglobin estimation.

# we present an optical detection technique of absorbed and reflected light. Absorption and reflectance spectroscopy at 940 nm and absorption spectroscopy at 1300 nm are implemented for detection of the Hemoglobin molecules. The obtained voltage from detector depends on the received light intensity. After placing the fingertip between emitter and detector, the voltage values are logged. Hemoglobin molecule concentration depends upon the change in light intensity.

#  During experimental work, blood Hemoglobin is measured through the invasive device SD check glucometer for validation of the non-invasive results. The reading is taken as referenced blood Hemoglobin concentration (mg/dl). At the same time, optical responses (in mV) through detectors have been collected from three channels simultaneously. During measurement, the channels data is collected in the form of voltages from three detectors. These collected voltages will be corresponding to referenced blood Hemoglobin concentration. These voltage values are converted into the decimal form using highly precise 4-channel ADS 1115 (from texas instruments) analog to digital converter [124]. The absorbance or scattering (resultant voltage values) is taken as 128 samples per second. The coherent averaging is done after logging the data from the ADS 1115. The coherent averaging has been done performed for the calibration of the device. During validation of the data, the averaging is done from 1024 samples which have been logged from ADS in 8 seconds.

# **4.3 Proposed Machine-Learning (ML) Method for Device Calibration**

# CNN models (RM) are calibrated to analyze the optimized computation model for blood Hemoglobin estimation. The detector’s output from three channels is logged as input vectors for prediction of Hemoglobin concentrations.

#

# Figure1.3 Estimation Block Diagram.

# The calibrated models are used to predict the blood Hemoglobin concentrations for validation. The collected data from the samples are required to be converted in the form of estimated blood Hemoglobin concentration values. It is necessary to design an optimized kernel for precise measurement of the predicted Hemoglobin concentration value. 97 samples are taken for device calibration which includes prediabetic, diabetic and healthy samples.

**5 PPG CALCULATION**

There are some properties that vary from person to person which could influence the PPG reading such as the circumference of a subject's finger, the different body fluid concentration, and the roughness of the skin that can cause the scattering of light, etc. In order to avoid this influence and improve the system performance, each person is required to perform ten measurements in order to construct his private individual calibration model, the blood glucose concentration of each person is then predicted based on his private individual calibration model. After smoothing the PPG signal using the Butterworth filter, the calibration model between the PPG data and reference values of BGC was built as shown in Figure



# Figure 1.4 PPG Work Flow.

The mean value of voltage is calculated from the peaks of PPG data obtained, as there exists a functional relationship between the PPG signal and blood glucose level [24], the voltage intensity of PPG signal changes with variation in glucose concentration. Ten means voltage is calculated from ten PPG readings for the same subject and put into a vector and put the ten reals GCB readings for the same subject into a vector, then used the two vectors as input data for constructing the regression model.

 (1)

 (2)

Where  Vector voltages PPG readings.

  : Vector reals GCB readings.

To construct the regression model, the regression line must be calculated. The general linear regression model is given by:

  (3)

Where Y: The predict blood glucose concentration.

X: The voltage of the PPG signal.

The (m) and (b) are the regression coefficients which is given by:

  (4)

  (5)

Where  the mean of vector voltages PPG readings.

 the mean of vector reals GCB readings.

**5 CONCLUSION AND FUTURE WORK**

We have successfully designed and developed a non-invasive Hemoglobin measurement device for universal healthcare. NIR light with specific wavelengths has been determined and validated using experimental analysis for Hemoglobin molecule detection. A multiple short wave spectroscopy technique is implemented to develop the proposed device. An optimized CNN model is analyzed for precise Hemoglobin estimation. The developed device has been calibrated and validated through healthy, prediabetic and diabetic patients. With the active support of the diabetes center, real-time testing has been done directly through all types of patients. The proposed device has been integrated with proposed framework for patient monitoring, cloud access by the patient and doctor and storage of Hemoglobin values. The error analysis has been done using Clarke error grid analysis of healthy, prediabetic and diabetic patients individually and combined analysis has also been performed for cross-validation. Experimental analysis has also been performed to analyze the device stability using different objects for measurements. The proposed device has also been compared with previously published approaches based on non-invasive devices in terms of error analysis and limitations of devices. During analysis, it is concluded that the proposed device is more precise for serum Hemoglobin measurement compared to capillary blood Hemoglobin measurement. Hence, a non-invasive Hemoglobin measurement device with the integration of proposed framework has been introduced for smart healthcare in this work.

 **6 REFERENCE**

[1] Brown J Vistisen D Sicree R Shaw J Nichols G. Zhang P, Zhang X. Global healthcare expenditure on diabetes for 2010 and 2030. Diabetes Research and Clinical Practice, 2011.

[2] J. Venkataraman and B. Freer. Feasibility of non-invasive blood Hemoglobin monitoring: In-vitro measurements and phantom models. In 2011 IEEE International Symposium on Antennas and Propagation (APSURSI), pages 603–606, July 2011.

 [3] Sarah H. Wild, Gojka Roglic, Anders Green, Richard Sicree, and Hilary King. Global prevalence of diabetes: Estimates for the year 2000 and projections for 2030. Diabetes Care, 27(10):2569–2569, 2004.

[4] David R. Whiting, Leonor Guariguata, Clara Weil, and Jonathan Shaw. Idf diabetes atlas: Global estimates of the prevalence of diabetes for 2011 and 2030. Diabetes Research and Clinical Practice, 94(3):311 – 321, 2011.

[5] P. H. Siegel, A. Tang, G. Virbila, Y. Kim, M. C. F. Chang, and V. Pikov. Compact non-invasive millimeter-wave Hemoglobin sensor. In 2015 40th International Conference on Infrared, Millimeter, and Terahertz waves (IRMMWTHz), pages 1–3, Aug 2015.

 [6] S. M. Alavi, M. Gourzi, A. Rouane, and M. Nadi. An original method for non-invasive Hemoglobin measurement: preliminary results. In 2001 Conference Proceedings of the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, volume 4, pages 3318–3320 vol.4, 2001.

[7] X. Li and C. Li. Study on the application of wavelet transform to noninvasive Hemoglobin concentration measurement by nirs. In 2015 Fifth International Conference on Instrumentation and Measurement, Computer, Communication and Control (IMCCC), pages 1294–1297, Sept 2015.

[8] P. P. Pai, P. K. Sanki, S. K. Sahoo, A. De, S. Bhattacharya, and S. Banerjee. Cloud computing-based non-invasive Hemoglobin monitoring for diabetic care. IEEE Transactions on Circuits and Systems I: Regular Papers, PP(99):1– 14, 2017.

[9] P. S. Reddy and K. Jyostna. Development of smart insulin device for non invasive blood Hemoglobin level monitoring. In 2017 IEEE 7th International Advance Computing Conference (IACC), pages 516–519, Jan 2017.

 [10] P. H. Siegel, W. Dai, R. A. Kloner, M. Csete, and V. Pikov. First millimeterwave animal in vivo measurements of l-Hemoglobin and d-Hemoglobin: Further steps towards a non-invasive glucometer. In 2016 41st International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz), pages 1–3, Sept 2016.

[11] N. M. Zhilo, P. A. Rudenko, and A. N. Zhigaylo. Development of hardwaresoftware test bench for optical non-invasive glucometer improvement. In 2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), pages 89–90, Feb 2017.

 [12] S. I. Gusev, A. A. Simonova, P. S. Demchenko, M. K. Khodzitsky, and O. P. Cherkasova. Blood Hemoglobin concentration sensing using biological molecules relaxation times determination. In 2017 IEEE International Symposium on Medical Measurements and Applications (MeMeA), pages 458–463, May 2017.

 [13] M. W. Sari and M. Luthfi. Design and analysis of non-invasive blood Hemoglobin levels monitoring. In 2016 International Seminar on Application for Technology of Information and Communication (ISemantic), pages 134–137, Aug 2016.

[14] Lekha S. and Suchetha M. Non- invasive diabetes detection and classification using breath analysis. In 2015 International Conference on Communications and Signal Processing (ICCSP), pages 0955–0958, April 2015.

 [15] Jiang Li, Pankaj Koinkar, Yusuke Fuchiwaki, and Mikito Yasuzawa. A fine pointed Hemoglobin oxidase immobilized electrode for low-invasive amperometric Hemoglobin monitoring. Biosensors and Bioelectronics, 86:90–94, 2016.

 [16] Nevine Demitri and Abdelhak M Zoubir. Measuring blood Hemoglobin concentrations in photometric glucometers requiring very small sample volumes. IEEE Transactions on Biomedical Engineering, 64(1):28–39, 2017.

[17] Joseph Y Lucisano, Timothy L Routh, Joe T Lin, and David A Gough. Hemoglobin monitoring in individuals with diabetes using a long-term implanted sensor/telemetry system and model. IEEE Transactions on Biomedical Engineering, 64(9):1982–1993, 2017.

 [18] A. Sun, A. G. Venkatesh, and D. A. Hall. A multi-technique reconfigurable electrochemical biosensor: Enabling personal health monitoring in mobile devices. IEEE Transactions on Biomedical Circuits and Systems, 10(5):945– 954, Oct 2016.

 [19] A. Gani, A. V. Gribok, Y. Lu, W. K. Ward, R. A. Vigersky, and J. Reifman. Universal Hemoglobin models for predicting subcutaneous Hemoglobin concentration in humans. IEEE Transactions on Information Technology in Biomedicine, 14(1):157–165, Jan 2010.

 [20] G. Wang, M. D. Poscente, S. S. Park, C. N. Andrews, O. Yadid-Pecht, and M. P. Mintchev. Wearable microsystem for minimally invasive, pseudocontinuous blood Hemoglobin monitoring: The e-mosquito. IEEE Transactions on Biomedical Circuits and Systems, 11(5):979–987, Oct 2017.

 [21] M. M. Ahmadi and G. A. Jullien. A wireless-implantable microsystem for continuous blood Hemoglobin monitoring. IEEE Transactions on Biomedical Circuits and Systems, 3(3):169–180, June 2009.

[22] Giada Acciaroli, Martina Vettoretti, Andrea Facchinetti, Giovanni Sparacino, and Claudio Cobelli. Reduction of blood Hemoglobin measurements to calibrate subcutaneous Hemoglobin sensors: A bayesian multiday framework. IEEE Transactions on Biomedical Engineering, 65(3):587–595, 2018.

[23] I. Pagkalos, P. Herrero, C. Toumazou, and P. Georgiou. Bio-inspired Hemoglobin control in diabetes based on an analogue implementation of a β-cell model. IEEE Transactions on Biomedical Circuits and Systems, 8(2):186–195, April 2014.

[24] T. Kossowski and R. Stasinski. Robust ir attenuation measurement for noninvasive Hemoglobin level analysis. In 2016 International Conference on Systems, Signals and Image Processing (IWSSIP), pages 1–4, May 2016.

[25] L. P. Pavlovich and D. Y. Mynziak. Noninvasive method for blood Hemoglobin measuring and monitoring. In 2013 IEEE XXXIII International Scientific Conference Electronics and Nanotechnology (ELNANO), pages 255–257, April 2013.

[26] Y. Liu, W. Li, T. Zheng, and W. K. Ling. Overviews the methods of noninvasive blood Hemoglobin measurement. In 2016 IEEE International Conference on Consumer Electronics-China (ICCE-China), pages 1–2, Dec 2016.

[27] V. Dantu. Derivative spectroscopy in non-invasive blood-Hemoglobin analysis. In 2016 IEEE First International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE), pages 350–351, June 2016.

[28] N. K. Sharma and S. Singh. Designing a non invasive blood Hemoglobin measurement sensor. In 2012 IEEE 7th International Conference on Industrial and Information Systems (ICIIS), pages 1–3, Aug 2012.

 [29] Y. Tanaka, C. Purtill, T. Tajima, M. Seyama, and H. Koizumi. Sensitivity improvement on cw dual-wavelength photoacoustic spectroscopy using acoustic resonant mode for noninvasive Hemoglobin monitor. In 2016 IEEE SENSORS, pages 1–3, Oct 2016.

 [30] X. Zhao, Q. Zheng, and Z. M. Yang. Two types of photonic crystals applied to Hemoglobin sensor. In 2016 IEEE International Nanoelectronics Conference (INEC), pages 1–2, May 2016.

 [31] I. Gouzouasis, H. Cano-Garcia, I. Sotiriou, S. Saha, G. Palikaras, P. Kosmas, and E. Kallos. Detection of varying Hemoglobin concentrations in water solutions using a prototype biomedical device for millimeter-wave non-invasive Hemoglobin sensing. In 2016 10th European Conference on Antennas and Propagation (EuCAP), pages 1–4, April 2016.

[32] Y. Nikawa and D. Someya. Non-invasive measurement of blood sugar level by millimeter waves. In 2001 IEEE MTT-S International Microwave Sympsoium Digest (Cat. No.01CH37157), volume 1, pages 171–174 vol.1, May 2001.

[33] Jinjin Shao, Fan Yang, Fen Xia, Qingfeng Zhang, and Yifan Chen. A novel miniature spiral sensor for non-invasive blood Hemoglobin monitoring. In 2016 10th European Conference on Antennas and Propagation (EuCAP), pages 1–2, April 2016.

[34] P. H. Siegel, Y. Lee, and V. Pikov. Millimeter-wave non-invasive monitoring of Hemoglobin in anesthetized rats. In 2014 39th International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz), pages 1–2, Sept 2014.

[35] Sudha, T & Kuzhaloli, S & Yuvaraj, R & Nandini, N & Nagaveni, V & Vijayakumar, P. & Krishnan, Yuvaraj. (2020). Force Sensor based Strategy analysis of Foot Ulceration for Diabetic Neuropathy Patients.